



# Mass Reduction: The Weighty Challenge for Exploration Space Flight

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# Background

- Meeting nutritional and acceptability requirements is critical for the food system for an exploration class space mission. However, this must be achieved within the constraints of available resources such as water, crew time, stowage volume, launch mass and power availability.
- Due to resource constraints, exploration class missions are not expected to have refrigerators or freezers for food storage, and current per person food mass must be reduced to improve mission feasibility.
- The Packaged Food Mass Reduction Trade Study (Stoklosa, 2009) concluded that the mass of the current space food system can be effectively reduced by decreasing water content of certain foods and offering nutrient dense substitutes, such as meal replacement bars and beverages.

# Study Objectives

- Identify technologies required to formulate meal replacement options that would decrease the mass and volume of the food system, as well as decrease the crew time associated with meal preparation.
- Assess the nutritional content of the average breakfast and lunch meals in the current International Space Station (ISS) menu and use this data as basis for establishing meal replacement requirements.
- Develop meal replacement prototypes for breakfast and lunch meals.
- Design menus implementing meal replacements and calculate total mass savings.

# Methods

- Target nutrient ranges were established based on the nutritional content of the current breakfast and lunch meals in the ISS standard menu.
- A market survey of available commercial products produced no viable options for meal replacement bar or beverage products. New prototypes for both categories were formulated to meet target nutrient ranges.
- Samples of prototype products were packaged in high barrier packaging currently used for ISS and underwent an accelerated shelf life study at 31 °C and 41 °C (50% RH) for 24 weeks. Samples were assessed at the following time points: Initial, 6 weeks, 12 weeks, and 24 weeks.
- Testing at each time point included the following: color, texture, water activity, acceptability, and hexanal analysis (for food bars only).

# Results

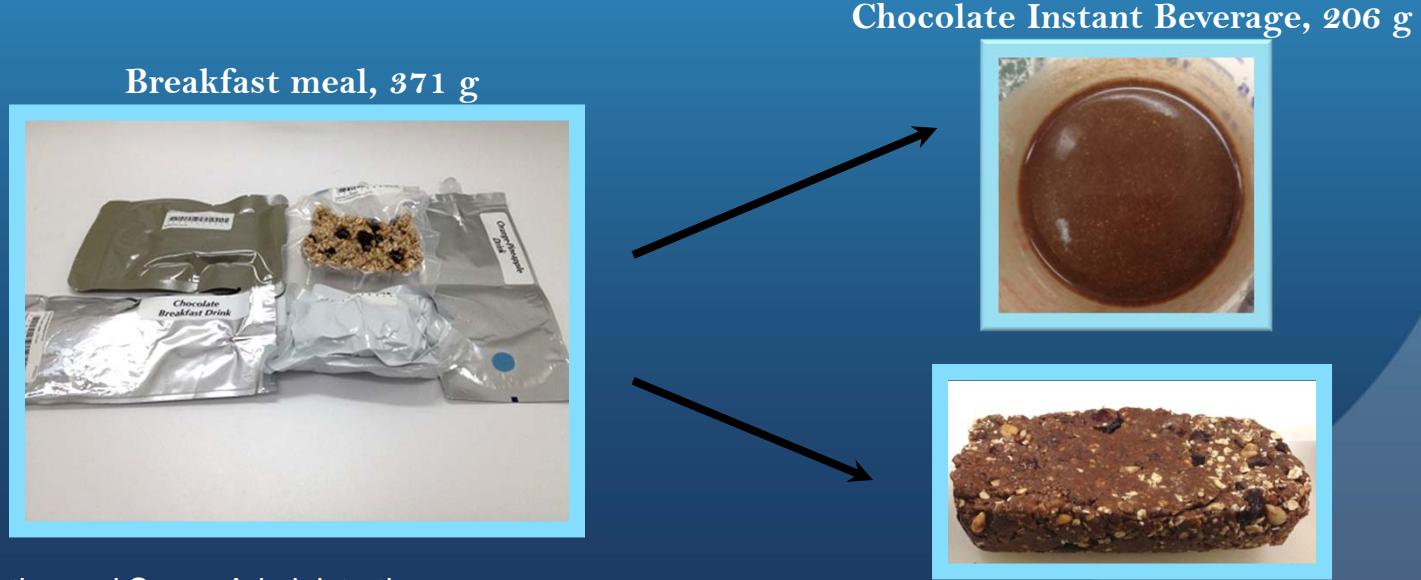
The Mass Reduction Trade Study (Stoklosa, 2009) used the 2009 ISS 10-day Standard Menu to identify targets for potential mass savings. Average macronutrient profiles of breakfast and lunch meals were computed with the following results.

Breakfast Meal Nutrients	Lunch Meal Nutrients
Mass: 304 g	Mass: 611 g
Energy: 736 kcal	Energy: 912 kcal
Protein: 24 g	Protein: 46 g
Carbohydrates: 122 g	Carbohydrates: 132 g
Fat: 20 g	Fat: 27 g
Saturated Fat: 8 g	Saturated Fat: 8 g
Dietary Fiber: 7 g	Dietary Fiber: 12 g

# Results

## *Breakfast Meal Replacements*

- Three different bars were developed. Each bar was approximately 50% lower in mass than the average ISS breakfast meal.
- Three different instant beverage prototypes were developed. One beverage is approximately 40% lower in mass than one meal, but requires 500 ml of water for rehydration. An average ISS breakfast meal requires approximately 450 ml of water for rehydration.



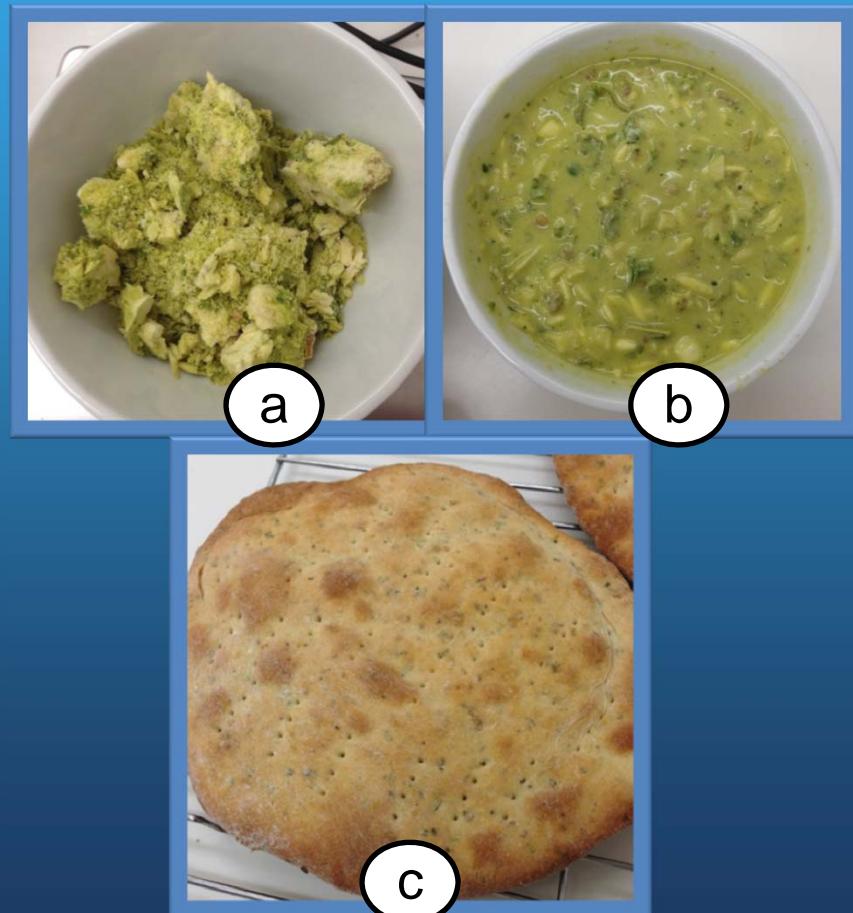
# Results

## *Lunch Meal Replacements*

- Developing a single meal replacement item to contain 900 to 1000 calories yielded large food bars with unpleasant off-flavors from the large quantity of protein.
- A combination of a rehydratable product and an intermediate moisture food product was found to be more acceptable and effectively reduced the mass of a lunch meal while delivering required macronutrients.

# Results

## *Lunch Meal Replacements*

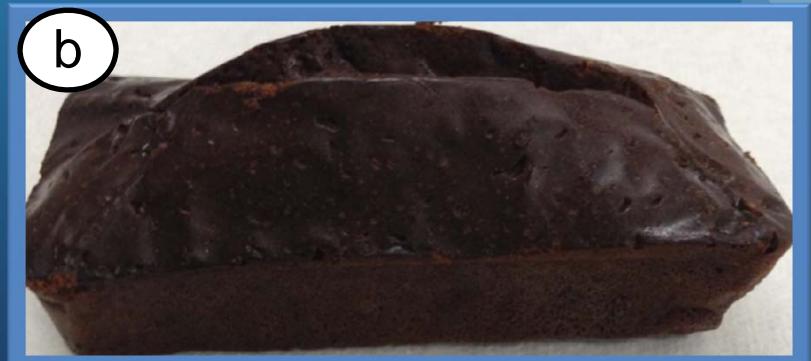
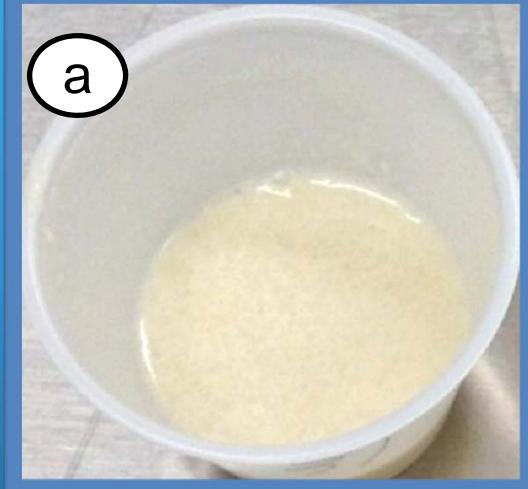


- (a) Freeze Dried Kale and Italian Sausage Soup, (b) rehydrated form, paired with (c) Italian Flat Bread
- An average ISS lunch meal including packaging weighs **691 g**. This soup and bread lunch replacement weighs approximately **221 g with packaging** and requires 500 ml of water for rehydration. ISS lunches require 250 to 510 ml of water for rehydration.

# Results

## *Lunch Meal Replacements*

- (a)Vanilla Instant Beverage paired with (b) Dark Chocolate Loaf.
- An average lunch meal including packaging weighs **691 g**. The combination of beverage and food bar weighs approximately **240 g** with packaging.



# Results

The breakfast and lunch meal replacements were developed within a target range of +/- 10% of the average nutrients in a breakfast and lunch meal. The table below compares the target nutrient ranges to the estimated nutrition delivered by the following meal replacement options.

	Mass (w/o packaging)	Calories	Protein	Fat	Carbohydrates	Fiber	Saturated Fat
<b>Target for Breakfast Replacement</b>	<228.1	<b>661 – 809</b>	<b>21 - 25</b>	<b>18 – 22</b>	<b>112 - 134</b>	<b>7.1 – 8.5</b>	<b>5.8 – 7.0</b>
Chocolate Peanut Butter	162.05	700	26	20	112	8	7
Crispy Trail Mix Bar	148.9	780	21	18	139	5	5.5
Peanut Butter Sandwich	161.8	680	22	20	109	6	5
<b>Target for Lunch Replacement</b>	<458.38	<b>820 - 1002</b>	<b>42 - 50</b>	<b>24 – 29</b>	<b>119 - 147</b>	<b>7.5 – 9.1</b>	<b>11-13</b>
Dark Chocolate Loaf & Vanilla Instant Drink	221.2	930	39	29	136	9	11
Pumpkin Loaf & Chai Latte Drink	215.5	950	40	25	142	6	10

# Results

## *Accelerated Shelf Life Study*

### Meal Replacement Food Bars and Breads

- Demonstrated up to 96-week shelf life based on acceptability scores.
- Samples increased in hardness over time likely due to protein aggregation.
- Samples became darker in color due to Maillard browning.
- There were no significant increases in hexanal concentration.
- No significant moisture or water activity changes occurred over time.

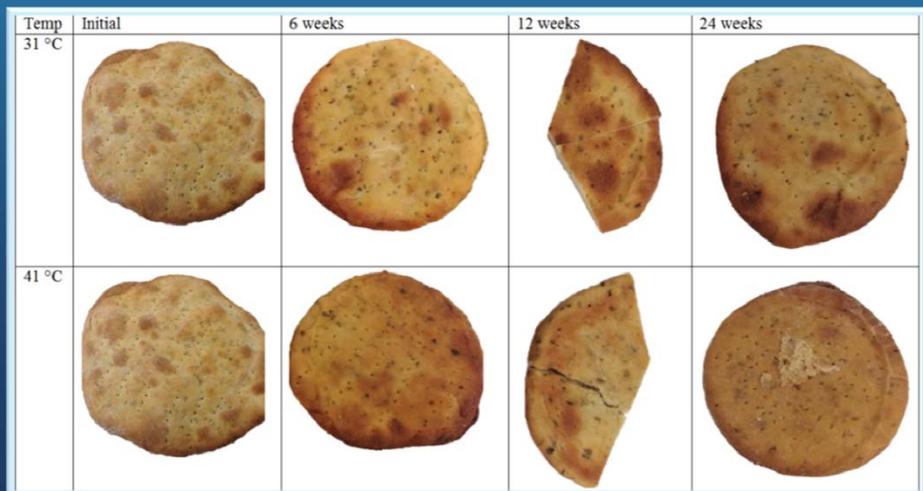
### Instant Beverages

- Changes in flavor and solubility were observed after 12 weeks of storage at elevated temperatures.

# Results

## *Accelerated Shelf life Study*

Chocolate Peanut Butter  
breakfast meal replacement bar  
throughout shelf life study  
stored at 31 °C.



Italian Flat Bread  
throughout shelf life study  
stored at 31 °C and 41 °C

# Results

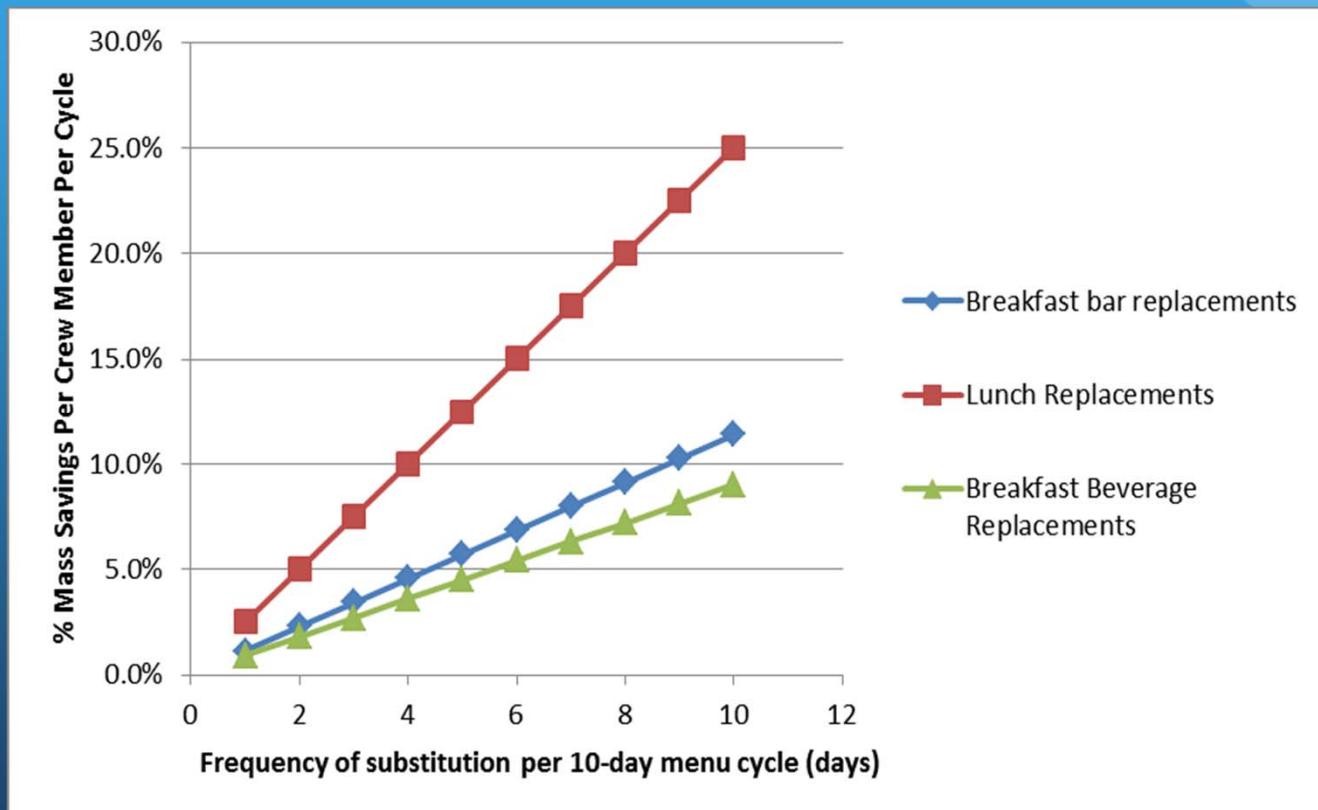
## *Menu Plans with Meal Replacements – Total Mass Savings*

Four 10-day Menu Plans Were Investigated

- Substituting **5** breakfasts with bars and **5** lunches with lunch replacements yields savings of **18.2%**.
- Substituting **7** breakfasts with bars and beverages and **3** lunches with lunch replacements yields savings of **14.8%**.
- Substituting all breakfasts with bars yields savings of **11.4%**.
- Substituting all lunches yields savings of **25%**

# Results

## *Menu Plans with Meal Replacements – Total Mass Savings*



# Discussion & Conclusion

- Proof of concept prototypes demonstrated that meal replacement food bars and beverages can deliver a comparable macronutrient profile while reducing the overall mass when compared to the ISS Standard Menu.
- Future work suggestions for meal replacement bars:
  - Reformulation to include ingredients that reduce hardness and reduce browning to increase shelf life.
  - Micronutrient analysis and potential fortification.
  - Sensory evaluation studies including satiety tests and menu fatigue.
  - Water Intake Analysis: The water in thermostabilized foods is considered as part of a crewmember's daily water intake. Extensive meal replacement would require further analyses to determine if additional water provisioning would be required per crewmember negating some of the mass savings.

- **Acknowledgments**

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# Questions?